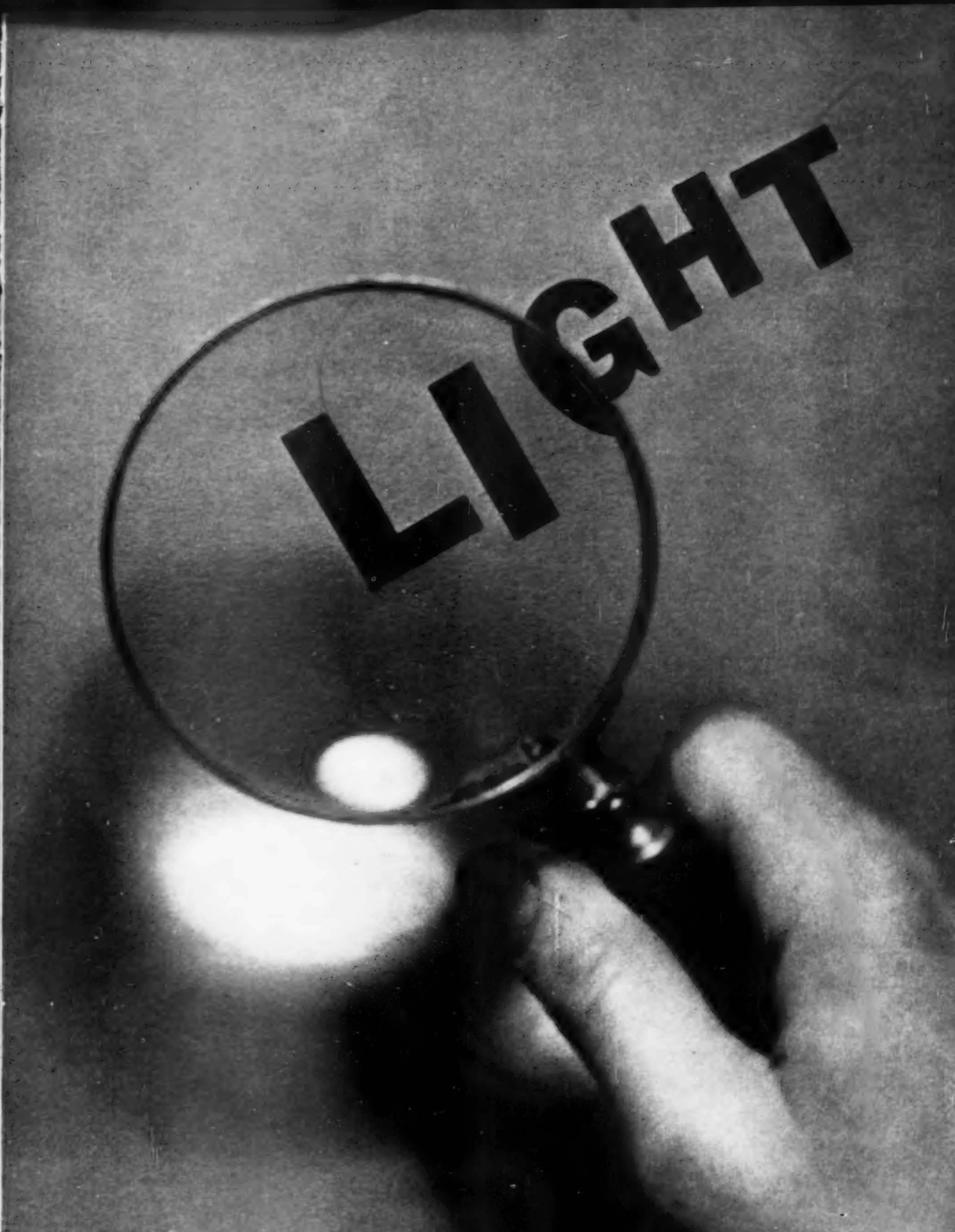


CORNELL SCIENCE LEAFLET

Volume 53, Number 3, February 1960, 25 Cents

CORNELL SCIENCE LEAFLET

Published four times yearly by
The New York State College of Agriculture
a Unit of the State University,
at Cornell University,
Ithaca, New York

Volume 53, Number 3, 25 cents **February 1960**

Second-class postage paid at Ithaca, New York

LIGHT

Verne N. Rockcastle

Wham! Did you feel something when you looked at that word? Do you feel anything striking you now? You cannot feel it as you would feel a ball, but *light* is striking your eyes with every word you read. The cover of this Leaflet, the words and pictures in it, and everything that you can see around you is visible because of light.

From the time you awake until you fall asleep, you depend upon your ability to *see*. Even when you are asleep, your dreams are often based on what you *saw*. Seeing is probably our most important sense, and the one we would miss most if deprived of it. Light is needed not only for sight, but also for many of the things we need to live—plants for food and clothing, and even oxygen to breathe! Without light we probably would not be here on earth!

The causes of light are not yet thoroughly understood, but many of its characteristics can be studied by both teachers and pupils. With simple, inexpensive equipment and a willingness to try things even when you have not done them before, you can learn much about this fascinating form of energy.

WHAT IS LIGHT?

Visible light is a kind of radiation that also includes radio waves, heat rays, infra-red rays, ultra-violet rays and x-rays. These radiations all travel very fast and usually in straight lines. They are like infinitesimal bundles of energy moving at fantastic speeds. Scientists call all the radiation from radio waves to x-rays *electro-magnetic radiation*. They do not know exactly what causes the radiations, but they do know how these radiations act when they strike various materials. They know how fast the radiations travel, and they know many ways to produce these radiations.

In air these bundles of energy move at the incredible speed of about 186,000 miles per second! They can move around the earth about seven times before you can say "Jack Robinson". Imagine traveling from New York City to Los Angeles in 1/75 of a second! Light can go from New York City to Los Angeles, back to New York, and to Los Angeles again (three times across the United States) in the time it takes for two successive flickers of a moving picture!

Light seems to be bundles of energy, but it also seems to travel in waves. Imagine the waves of a lake striking a pier—slap, slap, slap, slap. . . . . The top of each wave is its crest, and the bottom of each wave is a trough. From crest to crest of the next wave is the *wave length*. The wave length is also the distance from the trough between two waves to the next trough. As you read this, the bundles of light energy strike your eye just like tiny, tiny waves at a pier. However, the distance between light waves is only about 5-millionths of an inch. The wave length of red light is nearly twice that of violet light. When red waves, violet waves, and all the colors between these are mixed together, they appear white. White light is just a mixture of many colors.

Infra-red waves are longer than the longest visible light. Heat waves are still longer, and radio waves are the longest waves that we know about. They may be several hundred feet long. Ultra-violet waves are shorter than any visible light, and x-rays have extremely short waves. If you sent a beam of visible light across a pinhead, there would be about 15,000 wave crests between the edges of the pinhead. The shortest x-ray would have about 150 million wave crests in the same distance! Gamma rays, which are even shorter than x-rays, and are produced when radium atoms disintegrate (such as in a luminous dial watch), may have as many as 500 billion wave crests in one pinhead-width! Visible light, is only a tiny fraction of the many different wave-lengths present in the electro-magnetic spectrum.

The air around you is fairly alive with all kinds of electromagnetic radiation. There are all kinds of radio waves zipping by at thousands of miles per second. If you turn on a radio in your room, it can "feel" certain radio waves striking its antenna. A thermometer feels heat waves that strike it. A Geiger counter can feel short-wave radiation that your body cannot feel. Books could be written about each kind of radiation that flashes about you, but this Leaflet deals with only the kind that is visible. Future Leaflets may tell about other kinds of radiation.

SOURCES OF LIGHT

Most of our light comes from the sun, our nearest star. A tiny bit of light comes from the rest of the stars, but not enough to see by. The planets shine by reflected light from our sun, not by their own light. The moon also shines by reflected light from the sun. Sometimes you can see a faint outline of the rest of a crescent moon because of *earthshine*. Earthshine is sunlight that reflects from earth to moon and back to us.

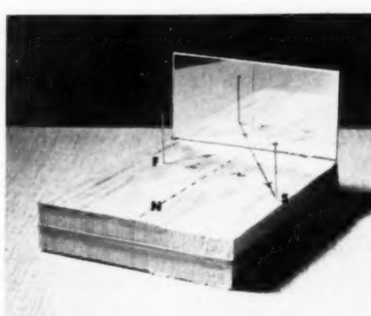
Burning is a source of light that dates back for thousands of years. When a candle, a paper, or a piece of wood burns, the heat produced

by the burning makes particles of carbon glow. In a candle flame, the bright yellow part of the flame is cooler than the bluish part below it. The yellow part is mostly glowing carbon.

Much of our light comes from artificial sources such as incandescent bulbs and fluorescent lights. Inside the incandescent bulbs is a tiny wire that becomes white hot when an electric current is sent through it. In a fluorescent tube, however, there is no long wire. Instead, there is mercury vapor inside the tube, and a coating of material on the inside of the tube that glows when the mercury vapor lights up. The mercury vapor lights up when an electric current is sent through it. However, the light produced by mercury vapor is mostly invisible light. It is light of very short wave length, shorter than violet. Such light is called ultra-violet. Ultra-violet light makes some minerals glow visibly, even though the light that strikes them is invisible. The inside of a fluorescent tube is coated with a fluorescent material that becomes light when ultra-violet light strikes it from the inside. Fluorescent lights are much more efficient than incandescent lights.

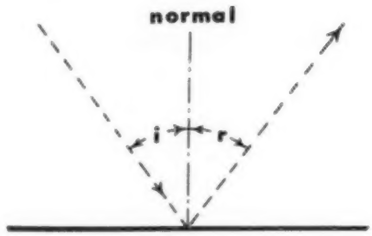
There are some other sources of natural light besides the sun and stars. Lightning beetles give off a cold light that is much more efficient than the best fluorescent light. Glowworms, the larvae of the lightning beetle, also glow. Many marine plants and animals glow, sometimes so much that waves and the wakes of ships can be seen clearly at night. This cold light is caused by oxidation of *luciferin,* a product of some living cells. Scientists are at work studying luciferin to learn more about this efficient lighting system. Perhaps some day you will use luciferin in some form instead of our less efficient lights.

Another kind of light comes from radioactive materials such as radium. When an atom of radioactive material decomposes, it gives off alpha and beta particles, and gamma rays. These rays are similar to X-rays. They cause some materials like zinc sulfide to glow when struck. The luminous parts of a watch or clock dial are coated with a mixture of radium salts and zinc sulfide. Each time an atom of radium decomposes, a tiny flash of light occurs in the zinc sulfide. You can



When the pin at the right is lined up with the scratch on the mirror and the image in the mirror, angle *i* will equal angle *r*.

see these flashes if you use a magnifier to look at a luminous dial in a completely dark room. You may have to wait for several minutes until your eyes become accustomed to the dark before you can see the flashes. Remember that for each flash you see, an atom of radium has disintegrated!



The law of reflection: $i = r$.

REFLECTION

When a rubber ball hits a wall at an angle, it bounces off at about the same angle. When light strikes a flat, polished surface such as glass, it reflects or bounces much as a ball would bounce. Physicists describe the reflecting of light from a smooth surface as a law of reflection: *The angle of incidence equals the angle of reflection.* This means that the angle of hit equals the angle of bounce. You can see this law at work in a simple experiment with a pocket mirror, some pins, and two blocks of wood.

Slide a knife blade carefully between the two mirrors of a double pocket mirror to separate them. With a nail and a ruler make a clean scratch across the center of one of the mirrors. Fasten this mirror to a block of wood with masking tape or with a rubber band, as shown. Stick a pin in the block about an inch from the mirror, and about an inch to the left of the scratch. Now look into the mirror from the right side of the block. Stick a second pin in the block so it appears to line up with the scratch and the first pin. Draw a pencil line from each pin to the scratch. With a protractor draw a line at right angles to the scratch.

Label the first pin "F" and the second pin "S." Label the right-angle line "N," meaning *normal.* A normal line is a line that is at right angles to something else—the mirror in this case. How does the angle between "F" and "N" compare with the angle between "N" and "S"? Measure them with a protractor to compare them.

Label the angle between "F" and "N" *i*. Label the angle between "N" and "S" *r*. Angle *i* is the *angle of incidence.* Angle *r* is the angle of *reflection.* Can you write the law of reflection in your own words now?

Refer to the diagram above. Angle *i* is the angle of incidence. Angle *r* is the angle of reflection. In reflection of light, *i* is always equal to *r*. This law of reflection holds for both flat and curved surfaces, as you will see later.

Even young children can see for themselves that this law of reflection is true. Youngsters seated at some distance from a wall can

bounce a ball against the wall from one person to another. To do so, they must hit the wall about midway between them if they are the same distance from the wall. If they stand or sit at different distances from the wall, the ball must be bounced so that the angle of hit (incidence) must equal the angle of bounce (reflection). When you are at a basketball game, or a game of billiards, watch how the ball bounces from the backboard or the rubber bumper so that it makes equal angles.

Tape some pocket mirrors on a wall about head high and about 12 inches apart. Let children shine a flashlight into the mirrors to make it reflect to another person in the classroom. If the mirrors are placed on the front wall of the room and numbered or lettered, a child can guess at which mirror he must point his light to shine it at another pupil. Then he can try it to see how good was his guess.

How Tall For Full-Length Mirror?

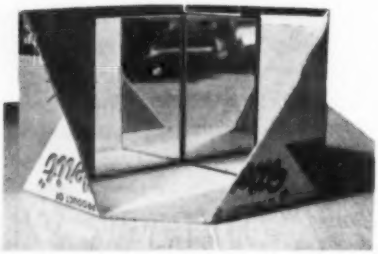
The reflection of light from a plane mirror has some interesting applications. Many persons think of a full-length mirror as one in which they can see both shoes and hat at the same time. They think that how much they see depends upon how far they stand from it. To find out for yourself, stand in front of a large mirror on the wall. Have someone use masking tape or crayon to mark the point on the mirror where the top of your head seems to be. Then have him mark the point where you see your belt or some other point on your clothing. Measure the distance from the top of your hair to that point on your clothing. Compare with the distance between the marks on the mirror. Now step back several feet and do it again. Does the distance from the mirror determine how much of yourself you can see? How long a mirror do you need to see your entire self?

See Yourself As Others See You!

When you look into a plane mirror and wink your *right* eye, an eye winks back at you, but it is the *left* eye of the person looking back at you. When we look at ourselves in a plane mirror we do not see what our friends see. We see ourselves *reversed*.

Now arrange two mirrors at right angles to each other, such as in the corner of a box as shown on page 8. Look into the mirrors along the diagonal and you will see yourself as others see you. The right eye of your image will wink back when when you wink your right eye. Try combing your hair in such a mirror! Can you do it?

If you add another mirror to the bottom of the box, so that the three mirrors come together at right angles, there is a still different effect.



Glue two mirrors in the corner of a box and you can see yourself as others see you.

When you look into this triple mirror with one eye, you can see your eye at the intersection of the mirrors. Triple mirrors have the unique ability to reflect a ray right back along the path that it came in. The ray from your open eye is reflected back along its original path until it meets your eye again. This mirror arrangement is of more interest than practicality. It did have some interesting applications during wartime, since it would reflect a tiny beam back to the person from which it originated without anyone else seeing it.

Periscope: See Up and Over

Periscopes and kaleidoscopes make interesting uses of mirrors. To make a periscope, arrange two plane mirrors at 45° from the horizontal so that their reflecting faces are parallel to and facing each other. The picture at right shows a completed periscope made from two pocket mirrors and a milk carton. With this simple periscope and some cardboard boxes, a first-grade class made the prize-winning submarine model shown on page 9. A child could lift the conning tower as shown, climb into the *Sea Wolf*, and look through the periscope at the world outside.

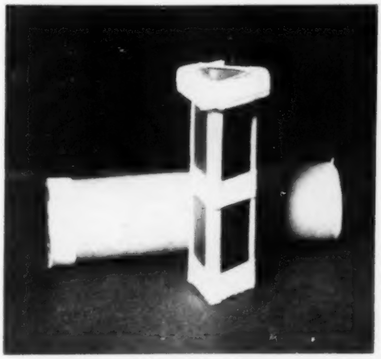
The periscope can be as long as you wish, but you will see less and less as the mirrors get farther apart. Also, as the periscope gets longer, the mirrors must be more accurately placed so that the light reflected by one is sure to strike the one below it.

The two mirrors in this periscope face each other at 45 degrees.

In the cardboard conning tower of this class-made submarine is a periscope made from a milk carton. A first-grader climbs in to look through it.

Kaleidoscope: Geometric Designs

You can make a kaleidoscope by fastening three strips of mirror together to make a triangular tube. A pocket mirror cut into three nearly equal strips taped together makes a good kaleidoscope. Mount this triangular tube of glass in a cardboard tube such as that from a toilet tissue roll. Make sure that the glass will not slip out and fall on the floor. Fasten a piece of plastic or waxed paper at the other end of the kaleidoscope. Drop in a few bits of colored paper and the instrument is complete. Hold it so that light strikes the translucent paper at the end, but not so that the colored bits fall out, then rotate the instrument, and you will see an ever-changing geometric design. The



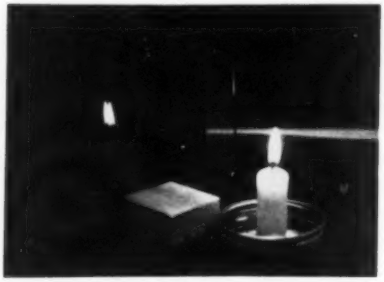
This simple kaleidoscope was made by taping three strips of mirror together and setting them in a cardboard tube.

mirrored tube multiplies the reflections of the colored bits of paper and gives the geometric images that the viewer sees.

DOUBLE REFLECTION AND GHOSTS

The split-image rangefinder on a camera is another use of mirrors. The mirrors used on these rangefinders, however, are not mirrors in the ordinary sense. Instead, they are prisms—solid pieces of glass with two faces at right angles to each other, and the third face at a 45° angle to the other two. Prisms are used instead of mirrors to prevent double reflection—a defect in ordinary mirrors.

To see what double reflection is like, hold a pocket mirror in front of you and turn it 45° to the side. Observe the reflection of something at the side of you. Now turn the mirror farther until your line of sight is nearly parallel to the mirror. Can you see a bright image of some object, then fainter images beside it? These faint images or ghosts are the reflections from the glass surface itself. The bright image is that formed by the silvered material on the back of the mirror. If mirrors were silvered on the front side, there would be no double image and the mirror could be used at any angle. If the silver were on the front side, however, it would scratch easily. Most mirrors are silvered on the back side where the silver is protected by the glass. Double reflections are seldom a problem because plane mirrors usually are not tilted.

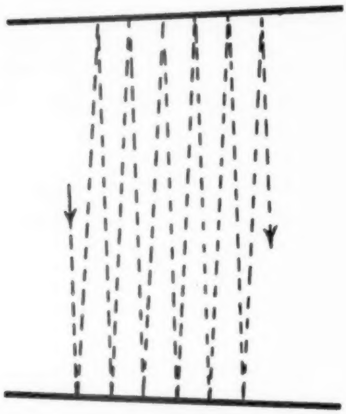


Two candle reflections are seen in this glass that is set at 45 degrees.

Some reflex cameras have a mirror that reflects the scene on a ground glass. When the shutter release is pressed, the mirror flips out of the way. These mirrors are silvered on the front side to prevent double reflection that would distort the scene as viewed in the ground glass.

When you look at a mirror next time, see if you can see a double reflection in it. You may need to tip or turn it to make a large angle of reflection that will allow you to see whether there is a double image. Making a mark on the front surface of the mirror will help to show whether double images result from reflections in it.

Have you sat in a barber's chair where there are mirrors on opposite walls and seen multiple reflections that make it look as if the room, the chair you sit in, and you yourself are duplicated many times?



Light rays will bounce back and forth many times between reflecting surfaces that are not quite parallel.

This effect is caused by the mirrors not being parallel to each other. If one is tilted a little, then the light rays bounce back and forth between the mirrors as shown in the diagram above. Can you see how this would make it look as if there were more objects than there really are?

CURVED MIRRORS

Some mirrors are not flat, but are curved like a section of a glass ball. They may be *convex* (arched toward you) like some auto rear-view mirrors, or they may be *concave* like some shaving mirrors. Convex mirrors make things look smaller, but they can reflect light from a wider area than the concave mirrors. Concave mirrors make close things appear larger, but distant things appear upside down.

Stand at one side of a classroom opposite a window. Hold a concave mirror in the hand farther from the windows, and a white card in the hand nearer the window. With the concave side of the mirror facing the card, reflect light from the window on the card, moving the card back and forth until you get a clear image. Is the image right side up or upside down? Concave mirrors can form *real* images on screens. Real images are ones that can be focused on a screen. They are inverted images.

Make a translucent screen from a piece of corrugated cardboard and some waxed paper or stencil backing sheet as shown on page 16. Set this screen in the slot of a block of wood and stand it on a table across the room from the windows. Hold a concave mirror such as a shaving mirror on the opposite side of the screen from the windows and focus the light from the windows on the screen. When you have a clear image, prop the mirror or have someone hold it while you examine the image with a hand magnifier. Is it enlarged? Is it upright or inverted?

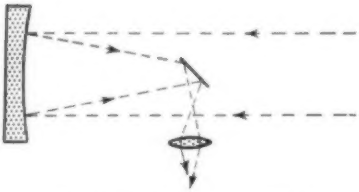
Keep the hand magnifier and the shaving mirror in the same position, but remove the screen. Can you still see the image? Is it clearer than before?

Placing a translucent screen between the hand magnifier and the shaving mirror helps to show that there is a real image formed by the

mirror, and that it can be magnified. Taking the screen away has no effect on the image at all except to make it brighter.

Reflecting telescopes. A reflecting telescope works on the same principle that you just observed. A concave mirror in one end of the telescope tube reflects light to a magnifier where it can be viewed or photographed. Since the viewer's head would be in the way of the light coming into the telescope if he were to look into the open end, a small 45° mirror is installed in the center of a reflecting telescope tube to reflect the light out through an opening in the side. At this opening is placed the eyepiece or the camera that records the light.

As contrasted with a refracting telescope (see page 18), a reflecting telescope has no optical defects until the light enters the first lens, which is at the eyepiece. It is lighter than a similar refracting telescope because it needs less glass. The base of the mirror can be hollowed out, and often is, especially in large mirrors such as that used in the Mount



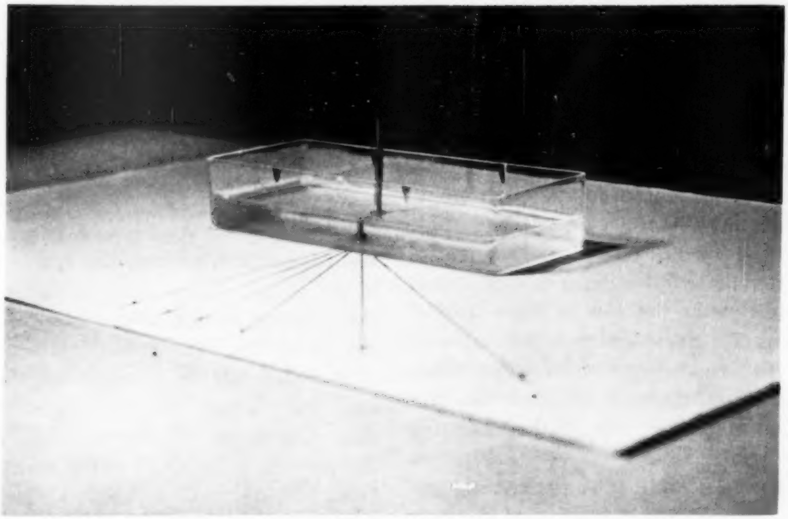
In a reflecting telescope, a 45 degree mirror reflects the light from the concave mirror to an eyepiece at the side of the instrument.

Palomar telescope, because only the curved surface needs to be polished. In lenses, however, two surfaces must be ground and polished, and all the glass between these two surfaces must be solid or nearly so. Also, light striking a mirror does not enter the glass, but merely reflects from its outer surface. Light striking a lens passes through it, and some of it is lost in the process.

REFRACTION

Have you noticed that olives, pickles and cherries appear larger in the jar than out of the jar? The slender, round jars in which they are sold bend the light in a way that magnifies their contents. This bending of light is called *refraction.* Light rays are refracted or bent whenever they pass from a material of one kind into a material of another kind. For example, light rays bend when going from air into glass or from glass into air. They bend when going from one kind of glass into another. They bend when going from air into water, or from water into air. Scientists do not understand completely why light rays bend when entering a different substance, but they have learned much about how and when they bend.

To do a simple experiment in refraction of light in water, get a rectangular plastic bow-tie box or cheese box (an aquarium will do,



The black lines representing rays of light coming from the submerged nail do not point to the actual nail.

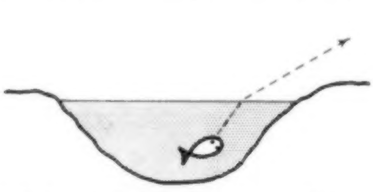
but will give more error because of its thick glass sides that bend light more than thin plastics do). Place the box over an "X" marked on a sheet of paper. Stand a slender nail upright in the box so that it is directly over the "X" on the paper. Half-fill the box with water. Mark the outline of the box on the paper. Now use a small ruler to sight along the paper toward the *image* of the nail as seen through the water in the box. Make sights from several different angles and draw the sight-lines to the outline of the box. Remove the box and complete the lines to the center of the "X". Are the lines straight where they cross the outline of the water-filled box?

Where each line of sight crosses the outline of the box, draw a line at right angles to the edge of the box. This line is called a *normal* (page 6). Can you measure the angle between it and a light ray from the nail to the edge of the box? This angle is called the *angle of incidence.* Is this anything like the angle of incidence for a light ray striking a mirror? (See page 6). When light goes from the nail out through the water, it goes in all directions—up, down, sideways. Some of the light rays strike the sides of the container at right angles. Do they bend at that point? Some of the strike the sides of the container at an angle. Do they bend

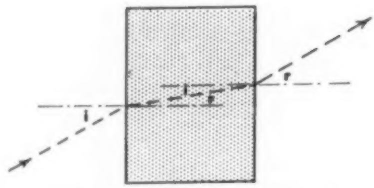
when they leave the container? Which rays bend most?

The angle between the normal (perpendicular line) and the ray after it leaves the plastic box is called the *angle of refraction*. How is it different from the angle of reflection? (See page 6.) Is the angle of refraction equal to the angle of incidence for a light ray that does not strike the side at right angles? In a *reflected* ray, is its angle of incidence equal to its angle of reflection? Does a reflected ray stay on the same side of the reflecting surface? Does a *refracted* ray stay on the same side of the refracting surface?

Make a table of the angle of incidence and the angle of refraction for each ray that you drew. Which angles are larger, the angles of incidence or the angles of refraction? Your table may show you a very important principle of light rays that pass from one material into another. When light passes from a dense material like glass into a thin material like air, it bends away from the normal. Imagine many light



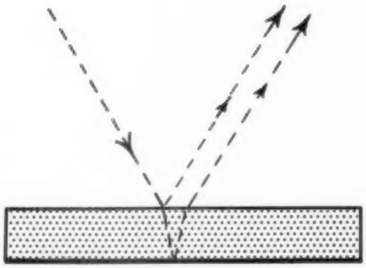
A light ray from a fish to an observer on the bank bends at the water surface, so the fish seems to be nearer the surface than it really is.



When a ray bends as it enters a dense material, *r* is less than *i*. As it leaves the material, *r* is greater than *i*.

rays coming from a submerged fish out into the air. A vertical ray strikes the surface at right angles and goes right on out without changing direction. One that strikes the surface at an angle bends away from the normal as shown above. Another light ray striking the surface at an even greater angle would be bent farther away from the normal. Your experiment with the nail and the plastic box with water showed this. When a light ray from the fish strikes your eye, you see the fish. The fish appears to be in line with the ray that strikes your eye, but if the ray bends when it leaves the water, *the fish is not where it appears to be*. The fish is usually below where it appears to be.

In the same manner, a ray of light entering the water bends at the water surface unless it strikes the water at right angles. A slanting ray entering a more dense material (such as one going from air into water or glass), bends toward the normal as it gets into the water or glass. In the example of the fish



When a mirror makes a double image, part of the light reflects from the front side of the glass, and part from the back or silvered side.

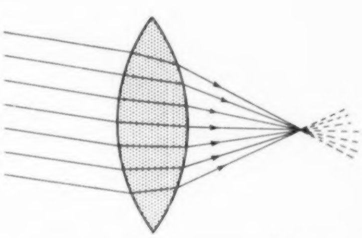
just described, you could not shine a flashlight at the point where you know the fish is, because the light beam would bend as it entered the water, and would miss the fish. You would need to shine it a little beyond the fish for the light beam to bend down toward the fish.

When light rays pass through lenses, they bend as they enter the glass, and they bend again when they leave the glass. Imagine a light beam entering a lens as shown at right. As it enters the glass, it bends toward the normal. When it leaves the glass, it bends away from the normal. In a flat piece of glass, however, the light beam bends a certain amount as it enters the glass, but bends the same amount when it leaves, so it leaves on a path parallel to the path by which it entered. The diagram on page 14 may help you to see this.

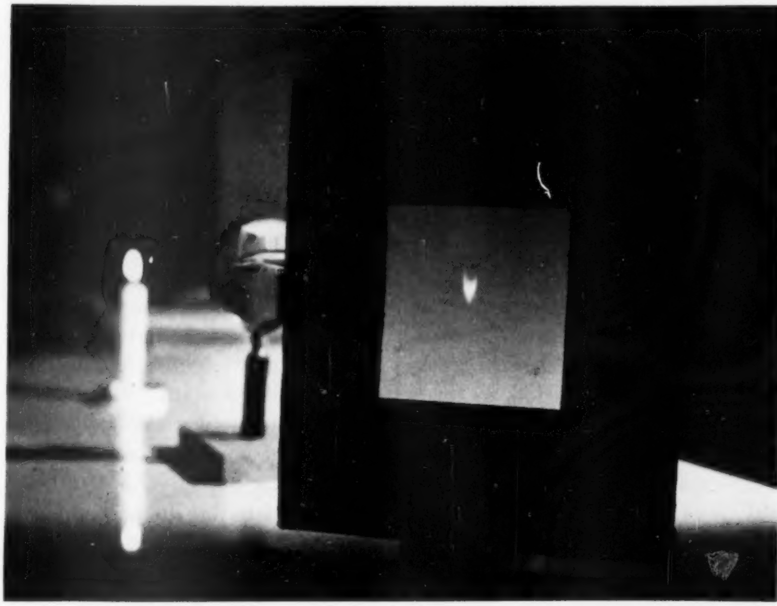
On page 10 you read about double reflection in a mirror that was at an angle to your line of sight. Can you see that a beam of light entering a mirror at an angle is refracted before it hits the silvered surface, is reflected, and is refracted again as it leaves the glass? Some of the light first striking the glass is reflected, too. Then some of the light that reflects from the silvered surface strikes the glass surface from inside the glass, and is reflected back to the silvered surface again. In this way, many faint images can be produced in addition to the bright one.

Convex Lenses

Below is a diagram of a lens that is thicker in the center than it is at the edge. Such a lens is called a convex lens. It converges the light rays that strike it. Sometimes it is called a converging lens. Convex or converging lenses are used in nearly all cameras, projectors, binoculars, telescopes and magnifiers. In some of these, a convex lens is used to form an image on film or on a screen. In others, an image is



A convex lens converges light rays that pass through it. Remember that the light rays keep going if nothing stops them.



The magnifier between the candle and the screen inverts the image on the screen. Can you look at an object with a magnifier so it is not inverted?

images, get a magnifier, a large white card, and a small flashlight like that shown on page 16. (Directions for making this simple light are given in *Electricity and Magnetism*, the Leaflet for Winter, 1956–57.) Set the light on a table, stand several feet away and try to focus the bulb on the card using the hand magnifier. Is the image smaller or larger than the bulb itself?

Now move slowly toward the bulb, keeping the bulb in focus on the card. Keep moving until the magnifier is much closer to the bulb than it is to the card. Has the image on the card changed? Can you measure with a ruler the height of the bulb and the height of the bulb's image on the card? How do these dimensions compare with the distance from the magnifier to the bulb and from the magnifier to the card? Can you see that as the distance from magnifier to card (screen) increases, the image gets larger and larger? Does it also become fainter as it gets larger? You must have a very bright light source to make a good picture on a movie screen at the end of a long auditorium.

Refracting Telescope. Replace

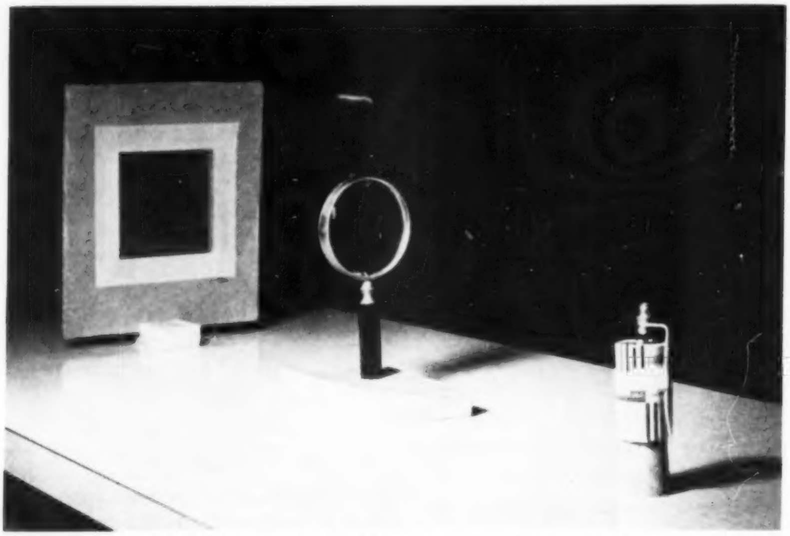
formed by one lens and then it is magnified by a second lens.

To see how a convex lens makes an image on a film or screen, stand across a room from a window. In the hand nearer the window hold a magnifier. In the other hand hold a white card. Move the magnifier toward or away from the card until a clear image of the window is formed on the card. What do you notice about this image? Is it upright or upside down? Is it smaller or larger than the window itself? Is the magnifier closer to the card or to the window?

Any image such as the one you see formed on the card is a *real* image. You can put a ruler next to the image and measure its length and width. You can trace around the image on a piece of paper. It is really there; it is not a figment of the imagination.

A Projector. Real images are always inverted and reversed so that the left side of the object is on the right. When you put a slide in a projector, it must be inverted and turned around so that when the convex lens in the projector projects the image on the screen it will be right side up and with the right sides where they should be. Some projectors are arranged so that you can put the slide upright into a carrier. Then the carrier rotates the slide before it is projected.

To see how a convex lens can make either smaller or larger real



The screen on which this simple flashlight is focused is made from cardboard, stencil backing and masking tape.

vex lens you can find it easily. It is the distance from the lens to its real image when it is focused on something far away like a window at the end of a room. The objective of your telescope should have a focal length of about 6 to 12 inches (150 to 300 millimeters). The eyepiece or ocular should have a shorter focal length, about 1 to 2 inches (25 to 50 millimeters).

How Powerful? To find the power of the telescope, divide the focal length of the objective by the focal length of the eyepiece. That is, if you use an objective with a focal length of 200 millimeters and an eyepiece with a focal length of 40 millimeters, the power of the telescope is 5 (200 divided by 40). Do not be misled by some magazine advertisements that show an inexpensive telescope of 25 power. Usually these advertisements use the word power to indicate the magnification in *area.* The telescope described above magnifies 5 *diameters* or 25 times the area, too. Makers of quality instruments do not use the term magnification to mean area. Magnification means the number of times the length or the height of an object has been increased when seen through the instrument.

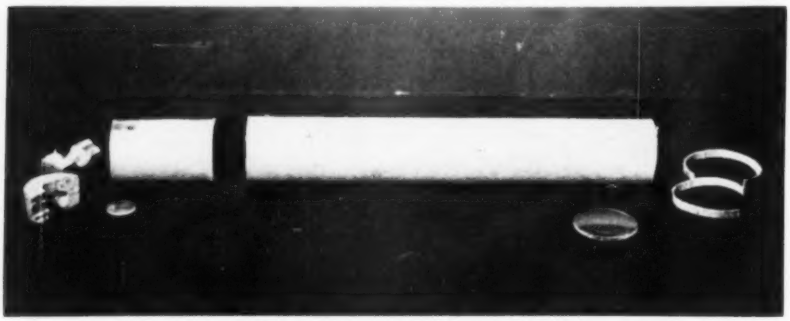
Opera Glass. An opera glass is different from an inverting telescope because it has a concave lens for an eyepiece. This means that you can see things right side up in an opera glass. However, opera glasses do not magnify as much as an inverting telescope. To

The objective lens of this opera glass is convex. The concave eyepiece is held between two halves of a cork in the movable tube.

the card in your experiment with a translucent screen (one that light will go through, but not clearly) made from cardboard and waxed paper. By cutting a slot in a small block of wood as shown on page 16, your screen will stand on a table while you focus on it. Drill a hole in another block of wood to hold the hand magnifier, as shown. Set your simple flashlight at one end of a table. At the other end, or on another table, set the screen. Place the magnifier in position to focus the bulb on the translucent screen. Now hold a small, but strong, pocket magnifier in back of the screen and focus on the image cast on the screen. Be sure that the small magnifier is nearly in line with the bulb, large magnifier, and image on the screen. Now ask someone to remove the screen while you continue to hold the small magnifier in place. Does the image remain bright and clear? Is it larger than the bulb itself? Your two convex lenses—a high power one near your eye and a low power one farther from your eye—make a simple inverting telescope.

In telescopes that use two convex lenses as you did, the farther lens or *objective* forms a real image inside the telescope near your eye. The lens that is next to your eye is the *eyepiece* (or ocular). It helps to magnify the image cast by the objective. Telescopes that have only these two convex lenses show things inverted. To see things right side up, you must have either a different lens arrangement or another lens between the objective and the eyepiece to turn the image right side up.

You can make a simple inverting telescope from a cardboard tube and a set of assorted lenses such as you can buy from the Edmund Scientific Company, Barrington, New Jersey. Pick out two convex lenses of different focal lengths. If you do not know the focal length of a con-

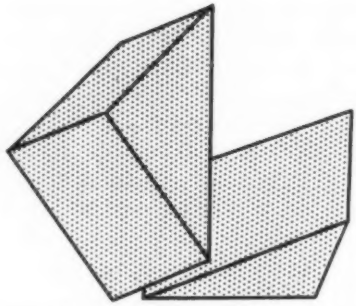


In this simple refracting telescope, cardboard rings hold the objective at right. The eyepiece is held by a split cork in the smaller, sliding cardboard tube at left.

make a simple opera glass, use a long focal length lens for an objective and a concave lens for an eyepiece. The concave lens should be more sharply curved than the objective. (This means that its focal length should be shorter, although a catalogue may give it as a negative focal length, meaning that it cannot make a real image as a convex lens does.) The picture on page 19 shows a completed opera glass made from a cardboard tube, a 200-millimeter objective, and a short focal-length concave eyepiece set in a hole in the cork. The drawtube is made from a piece of the cardboard tube with a section cut out to reduce its diameter.

If you can get an assortment of lenses, even though they are chipped or have other imperfections, try holding them in front of your eyes in different combinations and at varying distances from each other. You will learn much about how lenses work together by experiments with your assortment.

Binoculars. Do you wonder how a binocular can magnify so much and still not invert the image? A binocular has two sets of lenses like your telescope, but it has another mechanism for inverting the image. Modern telescopes and binoculars use prisms instead of a third lens. In each side of a binocular are two prisms. Each prism looks like an ice cube cut in half from corner to corner. One prism inverts the light rays from the objective. The next



Most prism binoculars have two prisms between the objective and the eyepiece. One is upright and inverts the image. The other is horizontal and reverses the image.

prism (set at right angles to the first, as shown above) reverses the light rays (left becomes right, and right becomes left). In this way the prisms do what an extra lens would do in the old-fashioned drawtube telescope.

Since the magnification of a binocular or telescope depends upon the focal length of the objective and a short focal length eyepiece, a long focal length objective (high power instrument) would make the telescope or binocular long. However, if the light can be sent around some corners as it does when it turns around in a prism, the length of the telescope can be shortened. The light follows an S-shaped path instead of a straight path.

Inexpensive imitation binoculars such as those in the five-and-ten look as if they contain prisms, but they do not. Instead, they are opera glasses (convex objective and con-

cave eyepiece) that are made to look like binoculars. Prisms are expensive to grind, and cannot be put into cheap glasses. Look at a very cheap binocular and see if you can see a concave lens for the eyepiece. In a real binocular you can see that a convex lens is used for the eyepiece. Look also to see if the objective of the real binocular is in line with the eyepiece. Can you see how the light must make an S-curve to get to the eyepiece?

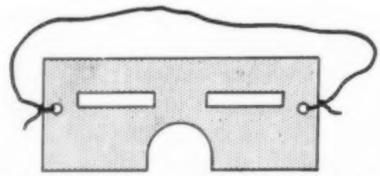
YOUR EYE IS A CAMERA

Your eye is very much like a miniature camera. At the front is an opening, the *pupil*, through which light enters the eye. Behind the pupil is a lens. The normal eye has a far better lens than the best lens that can be made. The lens changes shape instead of having to be focused in or out as on most cameras. At the back of the eye is the *retina* —a complicated screen of nerve endings. When light falls on this screen, the nerves send impulses to the brain where they are interpreted as pictures.

The lens in your eye is a convex lens. It forms a real image on your retina, and like all real images this one is inverted. You can see for yourself what the image on a retina looks like. Get a small candle and a partner in a dimly lit room. Sit so your partner's eyes are about 12 inches from your own. Light the candle and hold it midway between and slightly below yours and your partner's eyes. Move it slowly sideways while you look carefully into your partner's pupils. You will probably see a bright image in your partner's eyes that moves the same way the candle moves, and is right-side up. This is a reflection in the outer, moist surface of the eye. Now look carefully into your partner's pupil while you continue to move the candle back and forth sideways. Can you see a tiny spot of light that moves in the opposite direction? This is a real image on your partner's retina! It is tiny because the lens of the eye is much closer to the retina than it is to the candle. (Remember how the image of the bulb was small—page 16?)

Now blow out the candle, wait for a few seconds, and ask someone to switch on the lights in the room. Watch your partner's pupils as the lights come on. What do they do? The pupil regulates the amount of light that enters the eye. When the light is dim, the pupil gets larger. When the light is bright, the pupil becomes smaller and not much light enters the eye. In sunlight on snow the pupil is very tiny. Sometimes, the muscles of the pupil are not sufficient to limit the light entering the eye, and you squint to decrease the light.

You may wish to make an artificial squinter to use on a bright day. Cut a strip of cardboard (or use birch bark in an emergency) about 2 inches by 5 inches. Make a small hole near each end of the strip



Cut out an artificial squinter like this one and try it on a bright sunny day.

to hold a head string. Notch one long edge to fit around your nose. Make narrow slits for your eyes and tie the mask so the slits are in front of your eyes. This artificial squinter will make it easier for you to see on bright days.

THE CAMERA

A camera has a mechanical pupil, a lens that must be moved back and forth to change focus, and chemically treated film that stores whatever light strikes it before it is developed. When the light is bright, the pupil of a camera (or the aperture) must be made smaller. When the light is dim the aperture must be made larger. In cameras, f-stops are used to indicate the size of the aperture. Small numbers mean large openings. Large numbers mean small openings. Often the numbers on a camera are arranged so that each succeeding number doubles the size of the opening, or reduces it to half. For example, an f:5.6 opening has twice the area of an f:8 opening; an f:8 is twice as large as an f:11, and so on.

At small apertures (large f-numbers, such as f:16), objects both near the camera and far away are in focus. At large apertures (such as f:2 or f:3.5) objects at only one distance are in focus. Perhaps you have noticed how people who wear glasses squint when they look at something without their glasses. Squinting makes a smaller opening for the eye and things are in focus for greater distance. The distance through which objects appear in sharp focus is called the *depth of field*. The depth of field is great when the aperture is small (f:16), but the depth of field is shallow or slight when the aperture is large (f:2 or f:3.5).

A pinhole is such a tiny aperture that it has a tremendous depth of field. You can see this for yourself. Hold a pin upright about a foot from your eye and look toward a distant object. Can your eye focus on the pin and the distant object at the same time? Of course not!

Now prick a hole in a card, hold the hole close to your eye, and look again at the pin and the distant object. Can you see that both are fairly sharply outlined even though they are at different distances?

The lens is probably the most important part of a camera. In fine cameras the lens is not a single piece of glass, but many pieces cemented together or spaced with precision. A single lens, no matter how carefully it is ground and polished, does not refract light of different wave lengths to the same extent. Violet light is refracted more than red

This moderately priced camera is set for a time exposure focused at 25 feet, and has the diaphragm opened to f:3.5. Can you find these settings?

light. When a beam of white light strikes a single lens, the different colors that make up the white light separate a little and may strike the film or the screen in slightly different places to give an inferior image. In expensive lenses, however, several different kinds of glass are used in combination to bring the separated colors back together to make a high quality image on the screen or film. These color-corrected lenses, called *achromatic lenses,* may cost over a hundred dollars.

Another limitation of most lenses is that they are nearly perfect only at their center. Light rays that pass through the lenses near their edges are not refracted so well as those near the center. For this reason, inexpensive cameras have a diaphragm that does not open up very far. It limits the light entering the camera to the center section of the lens. The outer, less desirable part of the lens is not used.

Expensive cameras use a lens constructed of many elements or pieces, in which the outer part of the lens is improved over a single lens. In these cameras, the diaphragm may open wider and let light pass through the outer part of the lens without distorting the image. For this reason, a camera with an f:2 lens is an expensive one. Nearly the whole lens is used. A camera with an f:6.3 lens is usually less expensive, since only the central portion of the lens is used.

Besides the lens and diaphragm, all cameras have a *shutter*. This is a kind of shade that is closed except when you wish to take a picture. Then the shade opens, lets light strike the film, and closes again. In many cameras the shutter is made a part of the lens system. The speed at which the shutter opens and closes is adjustable on most cameras. If there is very dim light, or the object to be photographed is not moving, then the shutter may be opened and closed slowly, perhaps in 1/25 second. If the object is moving rapidly, or if there is bright light, then the shutter may be set at a faster speed such as 1/100 second. At slow shutter speeds a fast moving object makes a blur on the film, since the object would move a considerable distance while the shutter is open.

The Film

The film itself contains microscopic crystals of silver bromide, a light-sensitive chemical. When light falls on silver bromide it changes slightly. When this chemical is treated with a developer, the silver bromide becomes black wherever light fell on it, and transparent where no light fell on it. This piece of developed film is a *negative*.

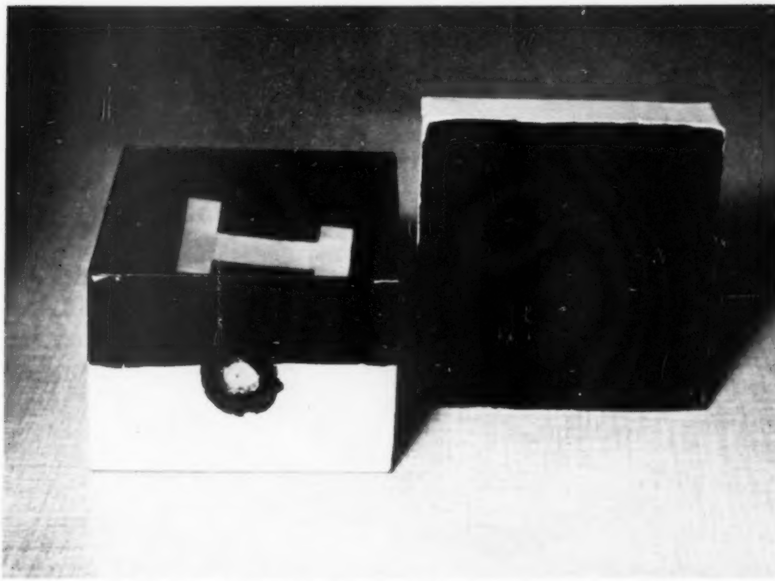
The Paper

To get a picture, the negative must be *printed*. Light is passed through the negative to a piece of paper coated with the same chemical (silver bromide) as the film. The black areas on the film prevent light from reaching the paper, and these areas remain white. Light passing through the transparent parts of the film strike the sensitized paper, and affect the silver bromide. The liquid developer later turns these portions black. So the original light conditions that made the negative are restored in the print.

MAKING A PICTURE WITH SIMPLE EQUIPMENT

You can make a camera, load it, take a picture, develop the negative, and print the final picture—all in your classroom. To make the camera, you will need a box about four or five inches square and about three inches high. It should have a snug-fitting cover that comes down at least an inch on the sides. Paint

The *lens* of this simple camera is a tiny hole in the aluminum foil in the black circle.



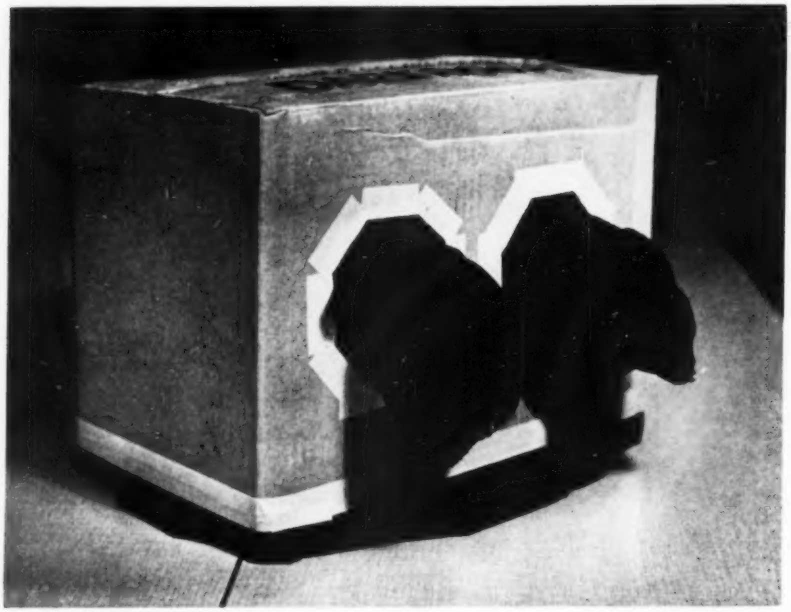
The masking tape in the back of this pinhole camera sticks the film in place. Remember to load the camera in complete darkness.

the inside of the box black, or cover the inside with black paper. Cut a half-inch hole in the center of one side. Over the inside of this hole paste a piece of aluminum foil. With a fine needle or a pin, prick a tiny hole in the center of the foil-covered opening. This will act as the lens of the simple camera.

In the side opposite the needle hole, fasten a piece of masking tape, as shown. This will be the film-holder. A piece of unexposed film can be pressed lightly against the tape and it will stay there while a picture is taken.

You will need a darkroom in which to load your pin-hole camera with film. Film is very sensitive to light, so you must be careful not to load your camera except in *total darkness.* To make a simple dark-room, get a cardboard box about 20 inches long, 14 inches wide, and 12 inches high. It should be sturdy. Cut the flaps from the top. Around the cut edge fasten a skirt of black cloth. A 6-inch strip of cloth can be taped along the inside edge of the box, then doubled over and taped along the outside edge to make a skirt of double thickness.

Cut two arm-holes in the side of the box as shown. Make two sleeves of black cloth, with a rubber band at the wrist, and tape these sleeves



This homemade darkroom has black cloth sleeves and a cloth border to keep out the light. It is painted flat black inside. You can set it right over a tray of developer and one of fixer.

to the openings so that no light enters when a person's hands are in the sleeves. Sleeves of double thickness are quite light-proof.

Paint the inside of the darkroom flat black, or cover it with black paper so that light does not reflect from the inside of the box. To use the box, set it on a large sheet of black paper, or a black cloth. To make doubly sure that no light enters the darkroom, use it only in a room with the lights off and the shades drawn.

The film that is best to use in your pinhole camera is Panatomic-X sheet film. This film is packed in boxes of 25 sheets, each separated from the next by a piece of black paper. When using this film with pupils, it is best to have individual sheets placed in discarded film boxes (ask a photographer to save them for you) so that if a pupil accidentally opens a box in the light, only one sheet of film is spoiled. Also, if your darkroom is not light-tight, you will find that out in working with the first picture. You will not spoil a whole box of film.

Load your pinhole camera in your homemade darkroom by plac-

ing a sheet of film against the masking tape in the back of the camera. Make sure that the notch in the edge of the film is in the lower right corner of the camera when the pinhole faces you. This will put the light-sensitive surface of the film towards the pinhole. Cover the front opening of the camera with a small piece of friction tape so that light will not enter until you want it to. Place the cover tightly on your camera before you remove it from the darkroom. It is now ready to take a picture.

To take a picture set your camera on something firm so it will not wiggle. Point it toward a sunny subject. Pull off the piece of black tape covering the pinhole and leave the camera undisturbed for about a minute. Replace the tape, and you are ready to develop your picture.

Dektol is a good commercial *developer* to use for your film. You can buy it at most photographic supply stores. Mix it with water according to directions on the can. This makes a stock solution that must be diluted further with water before using. To develop your film, dilute one cup of the stock solution with one cup of water.

The second solution you will need is *acid fixer*. You can buy this

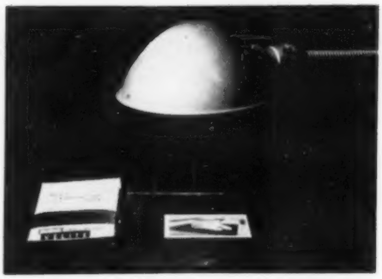
Here are all the things you need to make good prints: a light, developer, stop bath, and acid fixer. These commercial trays are excellent, but any glass or enamelled tray will do.

from a photographic store. Mix it with water according to the directions on the container. Do not dilute acid fixer before using it.

Put the diluted developer in a small enamelled or plastic tray, and acid fixer in another. (The 5x7 plastic trays such as those made by the FR Corporation and sold at most photographic stores are excellent, although any small glass, plastic, or enamelled tray will do.) Lay your camera with its exposed film next to the trays. Place the darkroom over the trays and camera and insert your hands in the black cloth sleeves.

Remove the film from your camera and place the film in the tray of developer. Move it around slowly in the solution for 3 minutes. Lift it out and place it in the acid fixer tray. Move it slowly in this solution for 5 minutes. Remove your hands from your darkroom, rinse and dry them, turn on the lights and look at your negative. Wash your negative in running water for about 15 minutes, then hang it up to dry. As you learn more about photography and cameras, you will be more exacting in your procedure, but for beginners the method described here will produce satisfactory pictures.

An examination of your dry negative will tell whether your exposure time in the camera was just right, too short or too long. If the negative looks very transparent, with little detail, then you did not ex-



A glass plate over your negative helps to hold it flat against the photographic paper when you make a print.

pose it long enough. If the negative is very dark, then perhaps you overexposed it. Experimenting with a few pictures, writing down what you did and what results you got each time, will help you learn the best combination for your camera.

To print your pictures you will need a package of Velite paper, a piece of clean window glass to cover the paper, and a desk lamp such as a goose neck lamp with a 60-watt bulb. You will also need to buy a stop bath. Mix it with water according to directions on the package.

You do not need a darkroom to print your negatives. A room that is not brightly lighted is satisfactory. Lay a sheet of Velite paper, shiny side up, on a table. Place the negative, shiny side up, on top of the paper and cover it with the piece of clean glass to hold the negative flat. Place a 60-watt bulb in a lamp so that it is about 8 inches above your negative. Turn the light on for ten seconds. Remove the glass and the negative.

Put your exposed paper in a tray of developer mixed by using 1 part stock solution and 2 parts water. (How is this different from film developer?)

Develop the print for 1 to 2 minutes, making sure that all parts of the paper stay under the solution. Move it around slowly. After 1 to 2 minutes (the picture should appear by this time), move the print to the stop bath for 20 seconds. Then move it to the acid fixer where it should stay for about 10 minutes. Finally, wash the print in running water for 15 minutes or more and dry it between blotters or paper toweling. If your print curls, press it between the pages of a large book.

As you learn more about picture-taking and making, you will refine your technique and perhaps use better and more expensive materials. The fundamentals of photography can be learned, however, with only these simple materials.

Light adds up on film!

As long as light continues to strike film, the image grows stronger. This property of film makes it useful for time exposures, where a picture can be taken even when there is very little light—too little light for our eyes to see. The most powerful telescopes use photographic plates instead of the human eye to record distant stars. We can see only the nearest and brightest stars, but the Mount Palomar telescope can "see" stars and other galaxies as far away as a half-billion light years! It can do this by taking a long time-exposure. The large mirror of the telescope gathers the light from distant objects and focuses it on a photographic plate. The light is too faint for the film to record in a short time, so the telescope is kept pointed at the same place in the sky for several hours while the tiny bit of light from a distant source keeps falling on the film. Finally, when it is developed, a tiny dark spot is left where the starlight kept hitting the plate.

OTHER LIGHT-SENSITIVE MATERIALS

Besides eyes and film, there are other materials that react to light. Some dyes used in cloth and paper fade when exposed to light for a long time. Your skin may become sunburned or tan when it is exposed to sunlight. The chlorophyll in green plants reacts with light to produce oxygen and sugars or starches from water and carbon dioxide. Light even causes certain elements such as sodium and cesium to give off electrons. These electrons may be used to control an electric current that will open a door, raise a garage door, or operate a machine. Such a device is called a photoelectric cell. You may see them in operation at supermarkets where doors open magically when you walk through a beam of light.

COLOR

The Reflected Fraction

Of all the light that speeds through the space around us, we see little white light. Most of it is colored. When sunlight strikes grass, most of it is absorbed and only the green light is reflected to our eyes. This makes the grass look green. When white light strikes a red book, all but the red light is absorbed. The red is reflected and the book appears red. As you look at the different colored objects around you, remember that each is reflecting to your eyes only a certain kind of light. When light of other wave lengths strikes, most of it is absorbed. A black surface *absorbs* nearly all the light that strikes it. A white surface *reflects* nearly all the light that strikes it.

The Transmitted Fraction

Get some pieces of colored cellophane. Try to get a red piece, a green piece, and one of another color. Look through the red piece at a white paper. What color do you see? Look at a red paper. What color do you see? Now look at a green paper. Do you see green? Much of the green light that was reflected by the green paper is absorbed by the red cellophane. Now try the same thing with green cellophane and with another color. By experimenting with colored cellophane and colored glass of different shades, you will learn much about how light rays are absorbed by some filters, but transmitted (let through) by others.

Color By Addition

When light rays of different wave lengths are added together, still different colors may be produced. The colored pictures in many books and magazines are made by using only three different colored inks, together with black. This is called a four-color process, although black is not really a color. Use a magnifier to look at a colored picture in a magazine. Can you see that it is made of tiny dots of red, yellow, blue and black? Where the picture is mostly red and blue dots, it appears green. Where it is mostly red and yellow, it appears orange. Look for different colors in a picture, then examine it closely to see what combination of dots was used to get that color effect.

Rainbows

White light becomes colored when it reflects from certain surfaces. White light also becomes colored when it passes through glass, water, and similar materials that refract the light. You have learned that white light is a combination of many wave lengths. Red light does not refract so much as blue light in glass or water. Yellow light refracts more than red, but not so much as green or blue. For this reason, a beam of white light striking a prism separates into a rainbow of colors.

You can see this for yourself by holding a prism in the sunlight and turning it so the light goes through it, bends, and strikes a white surface. (What would a rainbow striking a red surface look like?) Look for rainbows caused by light passing through glass jars, the bevelled edges of glass doors, and raindrops or dewdrops.

Drops of water in the air can refract the light that strikes them to make rainbows. When sunlight strikes a raindrop in just the right manner, it enters the drop, reflects from the back of the drop, and comes out again on the same side as the sun, but toward the ground. The raindrop refracts and reflects the sunlight to produce separate colors. If you stand with the sun at your back and look toward a rainstorm you may see a rainbow. You can see rainbows also when you look into the spray from a hose on a sunny day. Can you see a double rainbow in a spray, or in a rainstorm when the sun is shining?

Blue Sky, Red Sunset

Another cause of color in the sky is scattering. The air contains billions upon billions of tiny particles of dust, smoke, water, and other materials. When sunlight shines through this air, some of the blue light has difficulty coming through in a straight line. It reflects again and again from particle to particle until it finally arrives at the earth in an entirely different direction from where it started. The sky looks blue because the blue portion of sunlight finally reaches us by scattering in the air. Outside the atmosphere the sky is black except for the stars and other lighted bodies.

Red light can get through smoky air more easily than shorter waves. The rays from a setting sun pass through more smoky and dusty air than the rays of the sun at noon. Since only the red rays get through, the sun looks red instead of whitish-yellow.

There are many other interesting things about light for which there is no room in this Leaflet. As you experiment with light and read more about it, you may learn about polarized light, about mirages, about the rainbows caused by interference when oil spreads over water, and about interesting optical illusions. There are many more fascinating discoveries for you if you keep your eyes open and your mind curious and alert. Perhaps you will be one to discover something new about our world of visible energy.

Note: Because of limited space in this issue, it was decided to make sound the subject of a Leaflet for the 1960–61 school year, rather than include it in this Leaflet at the expense of light.

Some References To Help You

BEELER, N. F., and BRANLEY, F. M., EXPERIMENTS IN OPTICAL ILLUSION, *Thomas Y. Crowell, New York, 1951. 110 pages.* As the title indicates, here are many things to try and to look at to convince you that "seeing is not believing." Intermediate, upper.

FREEMAN, MAE and IRA, FUN WITH YOUR CAMERA, *Random House, New York, 1955. 55 pages.* Following some simple instructions for loading and using a camera, there are hints for taking pictures of people, landscapes, animals, and for some trick shots. Intermediate, upper.

KETTELKAMP, LARRY, SHADOWS, *William Morrow, New York, 1957. 64 pages.* Half of the book is an interesting treatment of shadow fun with silhouettes on a wall. The rest of the book describes earth shadows, moon shadows, shadows in photography and projected shadows with home-made slides. Intermediate.

PERRY, JOHN, OUR WONDERFUL EYES, *Whittlesey House, New York, 1955. 156 pages.* This rather complete description of the way our eyes work, supported by crude black and white sketches, includes some interesting and simple activities that help to amplify the text. Intermediate, upper.

ROGERS, FRANCES, LENS MAGIC, *Lippincott, Philadelphia, 1957. 158 pages.* This is a smoothly written description of the highlights in optical history. Beginning with the earliest lensmakers, the book describes Leewenhoek's microscope, Galileo's telescope, the exciting development and construction of the Mt. Palomar telescope and the modern camera. Upper.

ZIM, HERBERT, and BURNETT, R. WILL, PHOTOGRAPHY, *Simon and Schuster, New York, 1956. 155 pages.* This handy, concise reference book describes cameras, films, and picture-taking in general. Numerous illustrations in both black and white and in color support the descriptive text. Upper.